OPEN CHANNEL SIPHON
WITH VISCOELASTIC FLUIDS

Department of the Navy
Office of Naval Research
Contract N00014-67-A-0094-0002

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by

David F. James

Report No. E-144.1 February 1967

(*Reprinted from Nature, Vol.* 212, *No.* 5063, *pp.* 754–756, *November* 12, 1966)

Open Channel Siphon with Viscoelastic Fluids

VISCOELASTIC fluids show many remarkable phenomena[1], the best known of which is probably the Weissenberg effect[2]. Because such fluids produce normal stresses in a plane perpendicular to that in which shear takes place, they will climb up a rotating shaft (for example, a stirring rod) immersed in the liquid. A more direct illustration of the elastic properties of the fluid is provided when a rotating flow comes to rest; tracer particles within the flow indicate that the fluid first stops and then flows in the opposite direction for a short duration. An apparently unreported but equally spectacular effect with this type of fluid is the open channel siphon. The sequence of pictures in Fig. 1 illustrates the phenomenon; the upper 4 l. beaker was originally filled with a viscoelastic fluid, and it was then tipped slightly to start the liquid flowing over the lip of the beaker. Once established, the stream continued. The flow rate initially increased, then slackened off and finally stopped when the distance up the beaker wall became too great.

The fluids used for these experiments were solutions of polyethylene oxide in water, the concentrations ranging from 0·1 to 0·4 per cent by weight. The weight-average molecular weight of the polymer determined from the measured intrinsic viscosity in water according to the experimental relations of Shin[3] was $3{\cdot}8 \times 10^6$. This corresponds to approximately 10^5 units of the monomer —CH_2CH_2O—. The polymer is commercially available as 'Polyox', a product of the Union Carbide Company.

In order to determine the parameters which control the siphon phenomenon, the elevation between the beakers was varied, and Fig. 2 presents the results for a 0·3 per cent solution. The "climb" is the maximum distance from the free surface to the lip of the upper beaker, that is, when flow stops, and the "head" is the final difference in elevation between the fluid levels. The graph indicates the contrast with a regular siphon: the flow terminates when the climb becomes too great, and not when the two free surfaces reach a common level. It should be mentioned that, in an additional run with a 0·4 per cent solution at an elevation of 11 ft., the open channel siphon emptied the upper 4 l. beaker.

The concentration of the solution was also varied, and Table 1 presents the results for a fixed head of 11 in.

It was somewhat puzzling that the 0·2, 0·3 and 0·4 per cent solutions should be very effective in producing an open channel siphon, while the phenomenon disappeared altogether at 0·1 per cent concentration. This aspect of the problem was investigated further by a supplementary experiment using a standard tube siphon. It was found that, once the siphoning process had started, the end of the tube could be lifted above the free surface of the upper beaker with the siphoning action still continuing. Fig. 3 illustrates this remarkable result, which is another consequence of the elasticity of the liquid, and which lends itself more readily to systematic investigation. This phenomenon, which could be termed a "suspended flow-inlet", was mentioned to us by Dr. J. W. Hoyt in a private communication. We have since found that Fabula[4] has also observed the same phenomenon. Using a plastic tube with an inside diameter of 0·19 in., and at a head of 12 in.,

Table 1. EFFECT OF SOLUTION CONCENTRATION ON THE MAXIMUM "CLIMB" (CORRESPONDING TO THE CESSATION OF FLOW) AT A FIXED HEAD OF 11 IN.

Concentration (per cent by weight)	Viscosity (23° C, centipoise)	Maximum climb (in.)
0·10	3·9	0·0
0·20	10·5	3·4
0·30	36	4·2
0·40	60	4·7

The mean molecular weight of the dissolved polymer (polyethylene oxide) is $3{\cdot}8 \times 10^6$. The dynamic viscosities were measured with a size 200 Cannon-Fenske viscometer. (Viscosity of water at 20° C is 1·0 centipoise.)

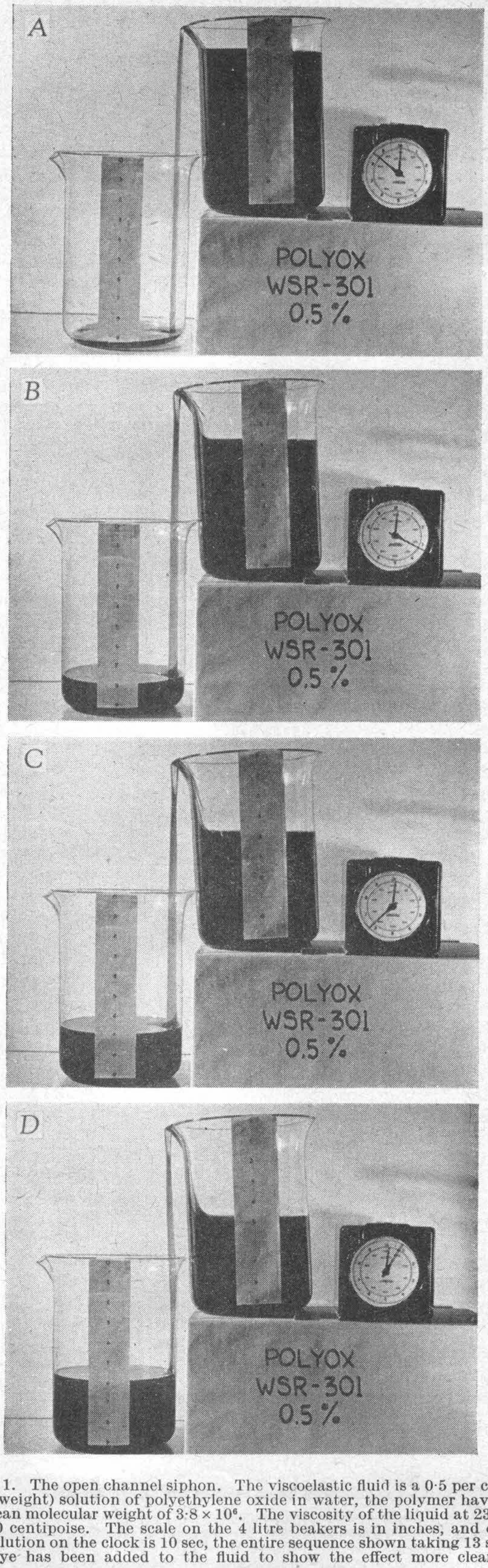

Fig. 1. The open channel siphon. The viscoelastic fluid is a 0·5 per cent (by weight) solution of polyethylene oxide in water, the polymer having a mean molecular weight of $3{\cdot}8 \times 10^6$. The viscosity of the liquid at 23° C is 80 centipoise. The scale on the 4 litre beakers is in inches, and one revolution on the clock is 10 sec, the entire sequence shown taking 13 sec. A dye has been added to the fluid to show the effect more clearly.

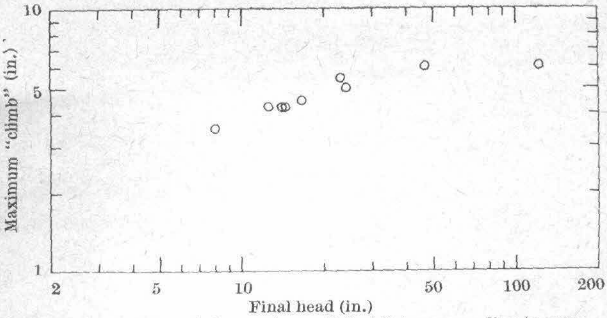

Fig. 2. Dependence of the maximum "climb" (corresponding to cessation of flow) on the head in the open channel siphon. The fluid is a 0·3 per cent (by weight) solution of polyethylene oxide in water, the polymer having a mean molecular weight of $3 \cdot 8 \times 10^6$.

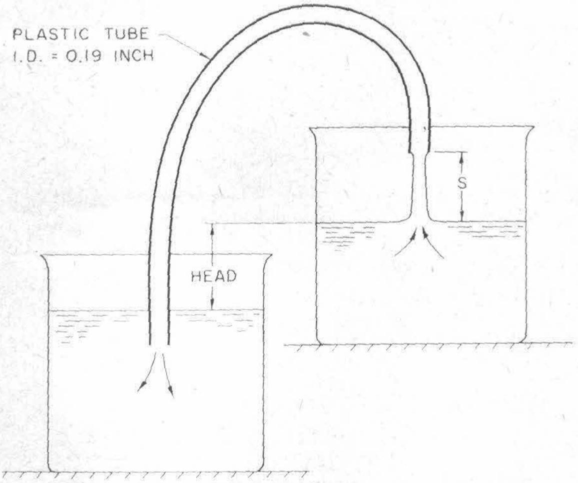

Fig. 3. The suspended flow-inlet with a viscoelastic fluid.

the maximum value for "S" was 1·3 in. for both the 0·2 and 0·4 per cent solutions. But with the 0·1 per cent solution, the distance S was reduced to 0·1 in., and would probably have been zero except for surface tension. When the head was increased to 60 in., however, the flow was noticeably faster, and values of 1 in. for S could then be obtained for the 0·1 per cent solution. It can be concluded from these observations that the deformation rate resulting from the faster flow was high enough to induce the necessary elastic stresses which allow the siphoning to continue when the tube end is suspended above the liquid. This fact, that the elasticity of the liquid depends on its rate of elongation, also explains why the open channel siphon will not work with the 0·1 per cent solution; when the beaker is initially tipped, and the fluid starts over the lip, the flow rate under gravity is too small to create the elasticity necessary for the open channel siphon to continue.

The experimental data refer to a material with molecular weight $3 \cdot 8 \times 10^6$. Further solutions were prepared with the same polymer at the lower molecular weight of $0 \cdot 5 \times 10^6$. Two solutions with concentrations of 1·0 and 2·0 per cent were tested, but neither would flow as an open channel siphon.

This work was supported in part by the U.S. Department of the Navy, Office of Naval Research. I thank Prof. A. J. Acosta for his comments on the manuscript.

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